CENTRIFUGAL FAN BLOWER

FRANK C. RICHARDSON

1898

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CENTRIFUGAL FAN BLOWER

Frank C. Richardson

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There is such a diversity of opinion as to the fundamental principles of the fan blower, which may be seen by referring to articles on the subject, that I decided to make the experiments partially independent of the methods pursued by others. That this difference of opinion is not due to want of experimental tests and data is apparent upon glancing over the many engineering magazines and other technical works: It has been mainly due to two defects; What to observe and How to observe it.

In experimenting with such a medium as air, its lightness, elasticity and susceptibility to all changes of pressure, temperature, humidity; small changes in one influence the others, all acting and reacting upon one another in a

manner which influences the results; thus making accurate observation and calculations very necessary. Due to the small quantities involved and their relations to one another, the observations must be made with as small a limit of error as possible; and this is the main difficulty in experimenting with a fan blower.

This thesis can be divide into three parts.

First, a means for measuring the quantity and pressure of air under pressure flowing through a pipe of known area.

Second, The variation of pressure and volume of air discharged with different sized openings at different speeds of the fan.

Third, The analysis of the power

required and accounting for it, is possible.

A Sturtevant Fan Monogram No. 4 was used. The diameter of the wheel is 17 inches, width at periphery of blades 4½ inches. The fan has six blades, each 3⅝ inches long, having an area of 18 square inches, and are of trapezoidal shape. There are two inlets, 8 inches in diameter, one on each side of the fan case; one of these openings is partially obstructed by the driving pulley 6 inches in diameter, while the other is obstructed partially by the shaft having 2 inches in diameter. Allowing for these obstructions the total inlet area is 66.27 square inches. The diameter of the shaft is 1¼ inches, having bearings 5 inches long at each end. The vertical diameter of the case is 30 inches and

the horizontal diameter 27 inches.
The wheel is placed 3 inches eccentrically in the fan case. The outlet is 10½ inches outside diameter; and over this a galvanized iron pipe 10½" inches inside diameter was fitted. This pipe is 5 feet long, and is provided with a tapered end, 1 inches long of 3½ degrees taper, making the diameter 9¼ inches at the end.

Two nozzles of different taper were used to vary the area of discharge. The taper of the nozzles being 3½ degrees and they were made to slip over the tapered end of the long pipe.

Diameter of No 1 3.915", Area of outlet 0.0836 □'
" " " 2 5.488", " " " 0.1643 □'

The power to drive the blower was furnished by a 5 h.p. Wood Gillet motor to which the blower was belted directly

by a belt $24\frac{2}{3}$ feet long, 4 inches wide, and of single thickness $\frac{3}{16}$ inch.

The motor is of the double horse shoe type, shunt winding, having a resistance of 99.5 ohms. The armature and series coils, of which there are six, have a resistance of .888 ohm. The brushes are of carbon, there being two placed side by side for each terminal.

The first part may be divided into two parts (a) Measurement of pressure in a pipe through which air is flowing (b) The measurement of the velocity and the pressure producing the velocity of the air.

In the measurement of the pressure in the pipe through which the air is flowing it is assumed that the air is perfectly elastic, and that the pressure is constant throughout the cross section

The pressure of the air in the pipe was measured by means of a manometer; one column of the manometer was connected by a rubber tube to a Pitot tube which could be moved vertically in a direction at right angles to the horizontal axis of the pipe. The manometer consists of a U tube of glass, containing distilled water, which is supported by a frame in such a manner that the columns are vertical. On the frame and in back of the columns is a scale graduated into inches and twentieths of an inch. When one leg of the U tube is connected by the rubber tube with the Pitot tube which is in the pipe, and the other leg is open to the atmosphere, the difference in the height of the water columns is proportional to the difference of pressure. The temperature being taken and the difference in height of water

column in feet. The excess of pressure = weight of one cubic foot of water at that temperature x h feet divided by 144 = pressure in pounds per square inch.

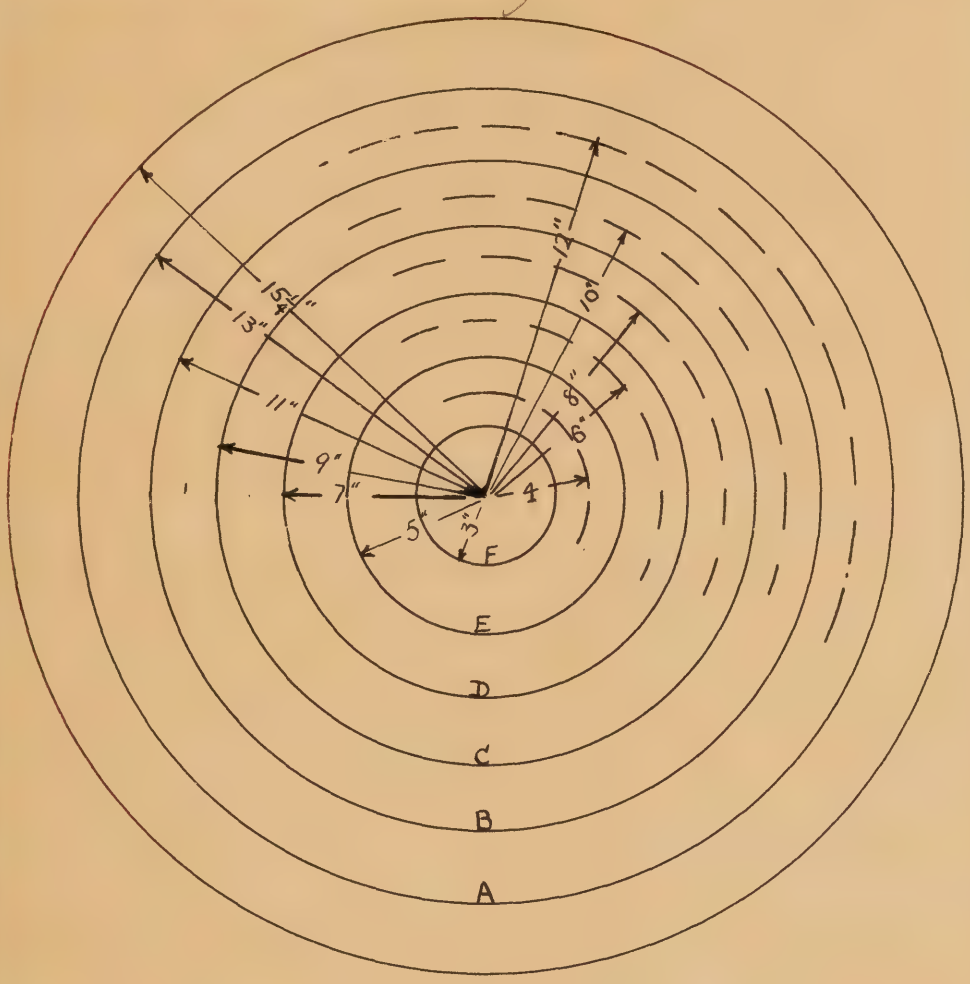
A glass tube $\frac{1}{8}$ inch inside diameter was introduced through the tube in the pipe, so that the plane of the orifice in the tube was parallel with the horizontal axis of the pipe. On moving this tube the pressure was found to decrease from the center to the bottom of the pipe, and there a vacuum was attained. This decrease in pressure across the pipe has been found to be due to what might be called an inductive effect. It would be caused by the air impinging on the tube and flowing off at an angle and also scooping the air out of the orifice, due partly to two causes; the tipping of the tube slightly caused by the pressure on it, and the

fact that edges of the orifice might not have been ground at right angles to the length of the tube. To overcome this an iron tube 9 inches long, $\frac{1}{4}$ inch inside diameter, was fitted with a brass plate $3\frac{1}{2}$ inches in diameter, this arrangement is called a Pitot tube. On placing this tube in the pipe and moving it up and down, the heights of the water columns in the manometer were found not to vary. In making the Pitot tube the disk was made as true a plane surface as possible, and the orifice in the tube made to coincide with the plane of the disk, so that the edges of the tube did not project out beyond the plane.

To measure the quantity of air entering the inlets of the fan a box 38" x 38" x 38" was built of planed and grooved lumber, and

lead surrounding the lower. In the top of the box there is an opening 30½ inches in diameter, having an area of 730 square inches. Holes were made in the side of the box for the belt; and after the belt had been running and drawn tight by the adjustable screw which moves the motor, pieces of leather were fastened on the side of the box so as to just clear the belt by this means; the error due to the opening disregarding the fact that the belt travels in opposite directions in passing through the two openings would be very small when considered with the errors due to the inaccuracy of the anemometer. Mr. Dunkin, a member of the Institution of Civil Engineers, London, conducted a series of careful experiments with the anemometer and found it to be

reliable within my 15%.



The anemometer was fixed to a stick 5 feet long 1 5/8 inches wide, and 1 inch thick marks were made on the stick two inches apart. When the stick was placed across the hole the upper plane of the anemometer

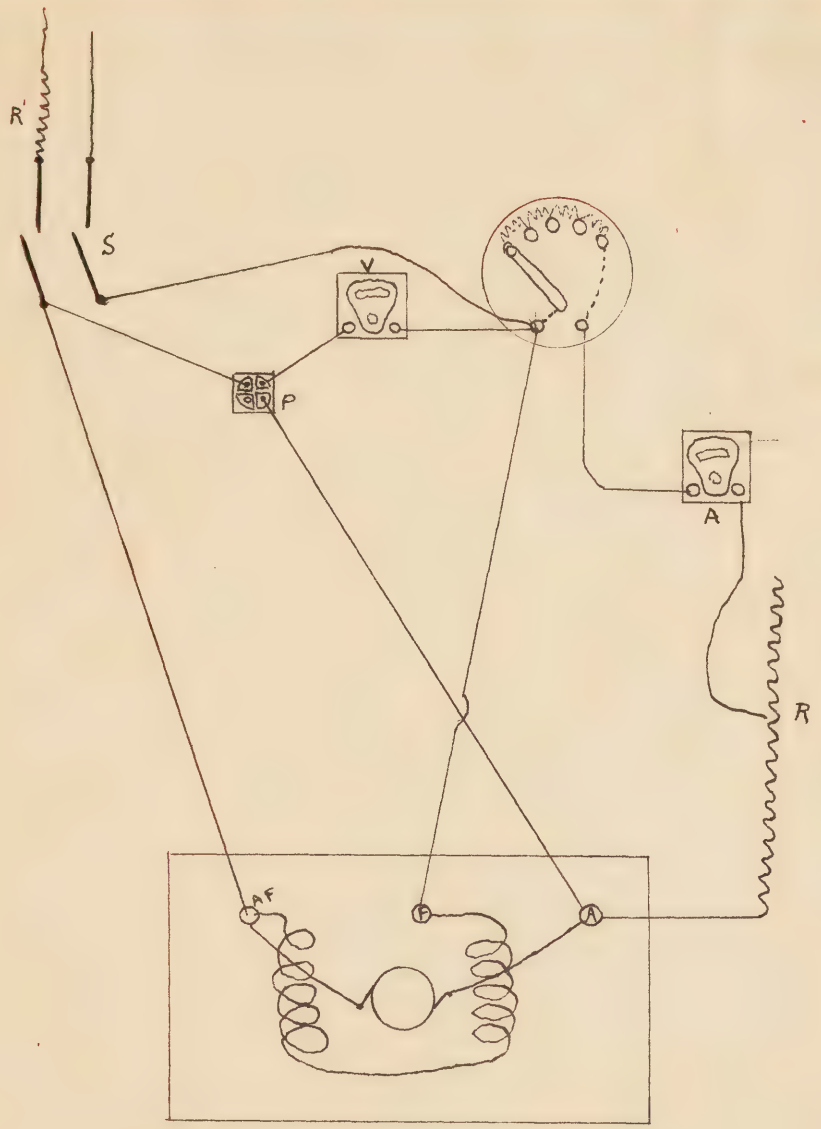
vanes coincided with the plane of the hole. For one speed of the blower readings of the anemometer were taken at A. B. C. D. E and F respectively, for a period of two minutes each. The circular hole was divided into rings as sketch shows, and the area of each ring minus the portion of the ring obstructed by the stick multiplied by the velocity of air entering that ring as indicated by anemometer gives the number of cubic feet of air entering; and the sum of these products for each section will equal the total quantity of air in cubic feet entering the blower. The quantities of air entering were determined for one minute in cubic feet. The barometric height was noted at frequent intervals and the temperature of the air entering the fan; also the temperature of the air in the

pipe. Knowing the height of the barometer the pressure of the air can be obtained, that is the pressure of the air entering the fan. The weight of air entering the fan can be found from the relation $PV = RTM$; as every thing in the equation is known except M the weight of the air in pounds entering the blower per minute. Having determined M_1 the weight of air entering the fan the volume of air passing through the pipe can be found from the equation $P_p V_p = R T_p M$. The air in passing through the fan is compressed and the compression was found to be adiabatic. The volume of the air passing through the pipe can be found then from the relation $P_F V_F^{1.4} = P_p V_p^{1.4}$. Using the equation $P_p V_p = R T_p M$ to calculate V_p and the relation $P_F V_F^{1.4} = P_p V_p^{1.4}$ to calculate V_p the values of

Vp agree thus proving the compression to be an adiabatic compression. The volume Vp of the air flowing through the pipe in cubic feet per minute having been determined the velocity of the air in the pipe is equal to Vp divided by the area of the pipe in square feet; area of pipe = .621 square feet

The second part of this thesis: the variation of pressure and volume of air discharged with different sized openings at different speeds of fan will be found in the tables which have been prepared from the results of the test.

The power furnished the motor was measured by means of Weston instruments voltmeter No 88 and ammeter No 89. The connections were made as shown in the sketch The switch S was then closed and the



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resistance in the starting box cut out; the resistance R' was changed until the voltage across the terminals of the fields was 105 volts: the slider was then moved along the resistance until the desired speed of motor was obtained. The current C, as registered by the ammeter A, flowing through the armature and the drop in voltage V as registered on the voltmeter, through the resistance R were noted. The speed of the motor was next obtained by means of a speed recorder reading from 1 to 1000 revolutions; this speed recorder has a rubber tip on the end of the spindle which was placed in the shaft end. The number of revolutions were taken for three minute periods and divided by three inorder to make the error in determining the speed of motor as small as possible.

A spindle was made to fit in the shaft

center of the fan and placed on the recorder, which was used to determine the speed of the fan. The calculated and indicated speeds of the fan were found to agree within a few revolutions, showing that the belt slip was very small.

The motor was run for a period of one hour, and the resistance of the field coils determined by means of a Wheatstone's Bridge every twenty minutes during the hour, and was found not to vary very much; the mean of the results being 99.8 ohms. = R_f

Electrical power given to the motor in watts = $C(V-V')j + Vc = C(V-V') + \frac{V^2}{R_f}$ and this divided by 746 gives the power put into the motor in horse power.

To determine the brake horse-power of the motor a Prony brake with an arm one foot long was placed on

the driving pulley of the motor. At the end of the arm is a knife edge which rests in an adjustable block on a pair of scales reading to $\frac{1}{8}$ of one ounce; by turning the screw in the block the level of the knife edge is brought to that of the center of the shaft. Water was kept running on the pulley to prevent it from getting hot. The slider was moved along the resistance R until the volt-meter indicated the drop V' of the result which I wanted to reproduce. The leather band on the brake was then tightened until the ammeter registered the current C of the result I was reproducing. The speed of the motor was then taken to see if it corresponded with the former speed and when the C and V' were the same as in the test I was reproducing, the speeds

were found to agree. A reading of the pressure on the scales was then taken. In the above manner all the results were reproduced to find the brake horse power corresponding to each electrical horse power for the different tests. The ratio of the brake to the indicated horse power gives the efficiency of the motor.

The weight registered on the scales has to have subtracted from it the weight caused by the brake and block to find this weight the strap was loosened the motor armature turned in one direction and a reading of the scales taken = 7lb 13 oz; the armature was revolved in the opposite direction, and the reading = 7lb 1 oz: the mean of these two gives the weight of brake and block = 7lb 7 oz. Brake horse-power

= 2 x length of brake arm in feet x π x number of revolutions of armature per minute x (weight indicated by scales – minus weight of brake and block) divided by 33 000.

The air is compressed in the fan, and as before stated this compression was found to be adiabatic. Work has to be done in order to compress the air and the amount of work done in foot pounds = $\frac{M}{.41} R (T_p - T_f)$

M is weight of air passing through the blower per minute.

R is a constant the value of which is 53.37 for air.

T_p temperature of air in the pipe.

T_f temperature of air entering fan.

The velocity of the air is changed by the fan from 0 feet per minute to v feet per minute; work is required

to do this. $F = MA$ and $W = FD$ which are evident from the definitions of force and work: the mass M = weight of air $\div (g = 32.2)$ and the acceleration $A = V$ which is evident. D the space passed through $= \frac{V}{2}$. $W = MAD = \frac{W}{2g} V^2$ = work done in foot pounds per minute

W is weight of air passing through fan per minute.

V is the velocity of the air in the pipe in feet per second.

To determine the transmission of the belt a jack shaft was arranged with a driving pulley 10.1248 inches in diameter; on the shaft was a pulley 2\.1242 inches in diameter with a face $3\frac{1}{2}$ inches wide. A leather belt 3 feet long $\frac{3}{16}$ inch thick by 2 inches wide was fastened to a spring balance which was fastened to the floor; the belt was

placed on the pulley and provided with a hanger for holding weights. Small blocks of wood were nailed to the belt to prevent it from slipping off over the edges of the pulley. The driving belt was placed on the driving pulley, the jack and the pulley of the motor. The connections were arranged for the motor the same as shown in sketch for previous experiments. Resistance R was changed until the drop in voltage corresponded to a drop obtained in a previous experiment; small weights were then added to the hanger until the ammeter indicated a current corresponding to the V. The speed of the motor and jack shaft were then taken by means of the speed indicator and the readings of the spring balances and weights added to the hanger

noted. The spring balance was detached from the belt and suspended by the hanger, the reading of the pointer was 1 lb 1 oz; in weighing the balance its weight was found to be two pounds and the difference of the two gives the zero reading of the balance = 15 oz.

The horse-power on the jack shaft = number of revolutions of shaft per min. × 20.242 × π × difference of reading of weight as indicated by balance and weights added divided by 12 × 33000.

Electrical horse-power given to motor $= C(V - V') + \frac{V^2}{R_f}$ divided by 746. Knowing the efficiency for about this horse power from the previous experiments the brake horse power of motor can be found; and the ratio of the horse-power indicated by jack shaft to brake horse-power of motor is the

efficiency of transmission of the belt. C

General readings taken for tests using nozzle No. I.

No	V	V'	C	F	M	P_1	P_2	$P_1 - P_2$	T_F	T_P	B	P
1	105	11	17.4	1959	1080	4.75	10.6	5.85	75.3	79	29.940	14.6953
2	105	24.5	14.5	1715	945	5.25	9.9	4.65	75.3	78.5		
3	105	33	12.4	1525	840	5.7	9.45	3.75	76	78	29.942	
4	105	42	10.4	1330	730	6.2	8.9	2.7	75.5	77		
5	105	50	9.2	1148	630	6.45	8.65	2.2	74.8	76		
6	105	59	7.6	945	520	6.85	8.25	1.40	73.8	74.3	29.944	

General readings taken for tests using Nozzle No. 1

	A		B		C		D		E		F	
1	268	280	253	266	230	246	220	238	208	230	199	219
2	250	265	235	250	220	238	205	226	198	218	186	208
3	214	234	205	220	200	220	190	212	180	204	165	193
4	185	208	175	200	180	204	170	198	168	178	170	198
5	164	193	150	180	148	179	145	177	143	176	138	171
6	118	152	111	148	113	149	108	147	104	142	99	137

General readings taken for tests using nozzle No. 2

No	V	V'	C	F	M	P_1	P_2	$P_1 - P_2$	T_F	T_P	B	P
1	105	27	18.5	1638	900	5.80	9.20	3.4	64	65.3	29.96	14.6883
2	105	37.5	15.1	1365	750	6.20	8.80	2.6	65	66		
3	105	50.5	11.7	1100	635	6.65	8.3	1.65	64.5	65.3	29.925	
4	105	57	10	1015	560	6.85	8.1	1.25	67.5	68		
5	105	63	8.6	891	490	7	8	1	68.8	68.3	29.90	

General readings taken for tests using nozzle No. 2.

No	A		B		C		D		E		F	
1	370	372	350	354	330	336	305	315	303	314	295	305
2	318	325	280	290	275	288	265	278	265	278	252	267
3	240	254	220	238	212	231	206	227	200	222	192	213
4	210	230	190	212	185	208	175	200	170	198	155	185
5	180	204	170	195	165	193	158	188	153	183	140	172

The numbers in the left hand [illegible]
indicate number of experiment and this
notation will be used hereafter.

V. the voltage at terminals of field.

V' the drop in voltage through R.

C. current in Amperes flowing through Armature.

F no. revolutions of fan per minute.

M No. revolutions of motor per minute.

P_1 height of water in inches in leg of manometer connected to Pitot tube.

P_2 height of water in inches in leg of manometer open to the atmospheric pressure.

T_F = temperature of air in degrees F of air entering fan.

T_P temperature of air in degrees F of air in the pipe.

B height of barometer in inches.

P pressure of the atmosphere in pounds per square inch as found from B.

A. B. C D. E and F are readings of the

anemometer in feet per at the sections as explained in the previous pages. The columns to the right contain the correct velocity of the air obtained from the calibration curve of the anemometer.

Test (1) reproduced,

No	V	V'	C	M	weights registered on Scales	True weight	
1	.05	11	17.4	1080	15lb 7oz	8 lb.	8.-
2	105	24.5	14.5	945	13lb 12oz	6lb 5oz	6.312
3	105	33	12.4	840	12lb 11oz	5lb 4oz	5.25
4	105	42	10.4	730	11lb 9oz	4lb 2oz	4.125
5	105	50	9.2	630	10lb 12oz	3lb 5oz	3.312
6	105	59	7.6	520	10lb	2lb 9oz	2.562

Test (2) reproduced.

No	V	V'	C	M	weights registered by scales	True weights	
1	105	27	18.5	900	16 lb	8 lb 9 oz	8.562
2	105	37.5	15.1	750	14 lb 6 oz	6 lb 15 oz	6.937
3	105	50.5	11.7	635	[illegible]	[illegible]	[illegible]
4	105	57	10	560	11 lb 5 oz	3 lb 14 oz	3.875
5	105	63	8.6	490	[illegible]	[illegible]	3.062

Results of test 1.

No	Electrical HP	Brake HP	Effic.	Volume entering fan	Pounds	Volume in pipe	Velocity in pipe	Pressure in pipe	Pressure in pipe above atmosphere
1	2.34	1.64	72%	1246	92.17	1234	1985	14.9063	.211
2	1.7033	1.1325	66.5	1176.4	87.066	1167	1833	14.8628	.1675
3	1.34	.838	62.5	1071.2	79.135	1064	1713	14.8305	.13525
4	1.025	.573	55	978.3	72.3383	9746	1567	14.7926	.0973
5	.826	.396	48	884.4	65.331	881	1420	14.7746	.0793
6	.616	.254	41.2	713.8	52.949	712	1145	14.7458	.0505

Results of test (2)

No	Electrical HP	Brake HP	Effic.	Volume entering Jam	Pounds	Volume in pipe	Velocity in pipe	Pressure in pipe	Pressure in above atmosphere
1	2.075	1.403	70.4%	.650.2	124.026	043	2640	14.8,18	.1225
2	1.52	989	65	1440	108.557	1433.5	2305	14.7821	.0938
3	1	.581	58.1	.149.8	86.864	1146.5	.845	14.7477	.0594
4	.741	.42	52.1	.031.1	77.3500	.028.7	.657	14.7334	.0457
5	.031	.285	45.2	94.4	70.595	939.8	15.3	.47235	.03605

Work accounted for test (1)

No	Comp. and changing Temp	Changing Velocity	Sum	HP
1	44392	573	45965	1.393
2	36267	1265	37532	1.1373
3	20602	1005	21607	.6547
4	14125	764	14889	45015
5	10205	569	10774	.3266
6	3446	300	3746	.1135

Work accounted for test (2)

No	Comp. and changing Temp	Changing Velocity	Sum	HP
1	16752	3760	20512	.6361
2	4131	2495	16626	.5038
3	9035	1280	10315	.3125
4	5035	917	6052	.1834
5	4595	700	5295	.16046

General readings taken for belt transmission efficiency

No	V	V'	C	Pull on spring balance	Weights added	Difference in pull	Revolutions of motor	Revolutions of jack shaft
1	105	1	13	5lb 7oz	1lb-1oz	4lb-6oz	1235	1345
2	105	1	12.1	4" - 8"	1" - 3"	3" - 5"	1230	1346
3	105	1	14.6	5" - 15"	1" - 11"	4" - 4"	1240	1342
4	105	1	13.8	8" - 7"	2" - 1"	6" - 6"	1242	1342
5	105	1	10.7	3" - 11"	0" - 15"	2" - 12"	1230	1340
6	105	1	9.7	2" - 11"	0" - 8"	1" - 3"	1224	1344
7	105	13	10.7	3" - 12"	1" - 4"	2" - 8"	1025	1130
8	105	12	10.3	4" - 0"	1" - 8"	2" - 8"	1055	1185
9	105	33	8.2	1" - 12"	0" - 4"	1" - 8"	834	910
10	105	33	8.2	1" - 9"	0" - 2"	1" - 7"	836	920

Results of transmission efficiency tests

No	Electrical H P Motor	Effic. Motor	Brake H P Motor	H P at jack shaft	Effic. transmission
1	1.96	70 %	1.37	.94	68.5 %
2	1.82	70 %	1.273	.714	55 %
3	2.18	72 %	1.577	.913	58.2 %
4	2.075	71 %	1.47	1.37	91.3 %
5	1.637	66 %	1.083	.59	54.6 %
6	1.5	65 %	.974	.47	48.2 %
7	1.467	63 %	.92	.453	49.1 %
8	1.43	62 %	.885	.475	53.7 %
9	.94	50 %	.47	.219	46 %
10	.94	50 %	.47	.2125	45.2 %

Efficiencies test (1)

No	Brake HP Motor	Work accounted on Fan	Ratio	Effic. of transmission	Power delivered to fan	Ratio
1	1.64	1.393	.85	60 %	.973	1.417
2	1.1325	1.373	1.0275	58 %	.641	1.775
3	.838	.6547	.781	53 %	.444	1.477
4	.573	.45015	.785	50 %	.2865	1.57
5	.396	.3266	.825	48 %	.190	1.717
6	.254	.1135	.363	45 %	.1407	.808

Efficiencies test (2)

No	Brake HP Motor	Work accounted for loss on Fan	Ratio	Effic of transmission	Power delivered to fan	Ratio
1	1.463	.6361	.435	60 %	.876	.725
2	.989	.5038	.509	55 %	.543	.926
3	.581	.3125	.538	50 %	.2905	1.0775
4	.412	.1834	.445	48 %	.1977	.949
5	.285	.16046	.562	45 %	.12825	1.25

The results of the tests, show that the HP ∝ about (air discharged)^3

Air discharged ∝ as the speed of revolution.

The tests made with the small nozzle as the discharge outlet, show that the velocity of the air in the pipe is less than that using the larger outlet, but the pressure is much greater, proving that what is lost in velocity is gained in pressure.

The results obtained from the transmission efficiency show that the method used for determining the transmission efficiency of the belt to be a very bad one; and I would not advise one to use it. The efficiency of transmission of a belt ranges from about 85% to 100%, and the efficiency of transmission of the belt in the experiment made should be about 95% instead

6 from 45 to 60 c.

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